

AI-Powered USB Handbook

USB

AI-Powered USB Handbook Team

© 2025 AI-Powered USB Handbook

Table of contents

1.	AI-Powered USB Handbook	4
1.1		4
1.2		4
2.	1 (Introduction)	5
2.1		5
2.2		5
2.3		5
3.	2 :USB (USB Connector Types)	6
3.1	USB	6
3.2	USB Type-A	6
3.3	USB Type-B	9
3.4	Mini USB & Micro USB	11
3.5	USB Type-C	13
3.6	USB	18
3.7		18
3.8		19
3.9		19
3.10		20
3.11		20
4.	3 USB (USB Transfer Protocols)	22
4.1	USB ?	22
4.2	USB	22
4.3	USB	22
4.4	USB 3.x	23
4.5	USB4	25
4.6		26
4.7	USB	28
4.8		29
4.9		30
4.10	FAQ	32
4.11		34
4.12		34
5.	4 Thunderbolt () (Thunderbolt Technology)	36
5.1	Thunderbolt?	36
5.2	Thunderbolt	36

5.3	Thunderbolt	36
5.4	Thunderbolt	37
5.5	Thunderbolt vs USB4	41
5.6	Thunderbolt	43
5.7	Thunderbolt	44
5.8	Thunderbolt	46
5.9	FAQ	47
5.10		49
5.11		50
6.	5 (Charging & Power Delivery)	51
6.1		51
6.2		51
6.3		57
6.4		58
6.5	USB PD (Power Delivery)	58
6.6	(E-Marker)	62
6.7		63
6.8		64
6.9		65
6.10		65
7.	6 (FAQ & Common Misconceptions)	67
7.1	FAQ	67
7.2		67
7.3		69
7.4		70
7.5	Thunderbolt	72
7.6		74
7.7		75
7.8		77
7.9		78
7.10		79

1. AI-Powered USB Handbook

AI-Powered USB Handbook

AI-Powered USB Handbook	USB	USB 3.2 Gen 2x2	Thunderbolt 4 (4)
Type-C			

1.1

- -
- **USB** - USB
- **USB** -
- **Thunderbolt** -
- - USB PD
- -

1.2

-
-
-
-

2. 1 (Introduction)

2.1

USB (Universal Serial Bus) Type-C

USB

USB 3.2 Gen 2x2

AI-Powered USB Handbook

USB

AI

2.2

- - 4 USB4
 - USB

2.3

- 1.
 2. USB 1.0 USB4
 3. Intel Thunderbolt USB
 4. USB PD PPS
 - 5.

3. 2 :USB (USB Connector Types)

USB

3.1 USB

3.1.1

USB 1996 Type-A Type-B

- MP3
-
-
-

[!IMPORTANT] 2024

USB Type-C

iPhone 15

Type-C

3.1.2 USB

```
timeline
title USB
1996 : USB 1.0 : Type-A / Type-B : 1.5Mbps ( )
1998 : USB 1.1 : 12Mbps ( )
2000 : USB 2.0 : 480Mbps ( ) : Type-A/B
2000 : Mini USB : Mini-A / Mini-B :
2007 : Micro USB : Micro-A / Micro-B : <br> Mini USB
2008 : USB 3.0 : 5Gbps ( ) : Type-A/B <br>
2013 : Micro USB 3.0 :
2014 : USB Type-C : <br> :
2017 : USB 3.2 : 20Gbps : Type-C
2019 : USB4 : 40Gbps : Type-C
2024 : Type-C :
```

3.1.3

Type-A - Type-A 1996 - USB 3.2 Type-A

Micro USB - 2007-2020 - Micro USB - Type-C

Type-C - 2014 Lightning - 2024 -

3.2 USB Type-A

USB

-
- 12mm × 4.5mm
- 1,500

3.2.1

USB 2.0 Type-A 4

1	VBUS	(+5V)
2	D-	
3	D+	
4	GND	

USB 3.0/3.1/3.2 Type-A 9

USB 2.0	4	5				
5		StdA_SSRX-				
6		StdA_SSRX+				
7		GND_DRAIN				
8		StdA_SSTX-				
9		StdA_SSTX+				

[!NOTE] USB 3.0+ 5 USB 2.0 4 USB 3.0 USB 2.0 4

3.2.2

USB-IF

/	USB 2.0	480Mbps
	USB 3.0/3.1 Gen 1	5Gbps
Teal	USB 3.1 Gen 2	10Gbps
	USB 3.2 /	20Gbps
/		BC 1.2

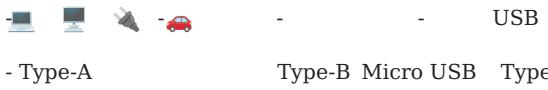
[!TIP] USB 3.0+ / USB 2.0

3.2.3

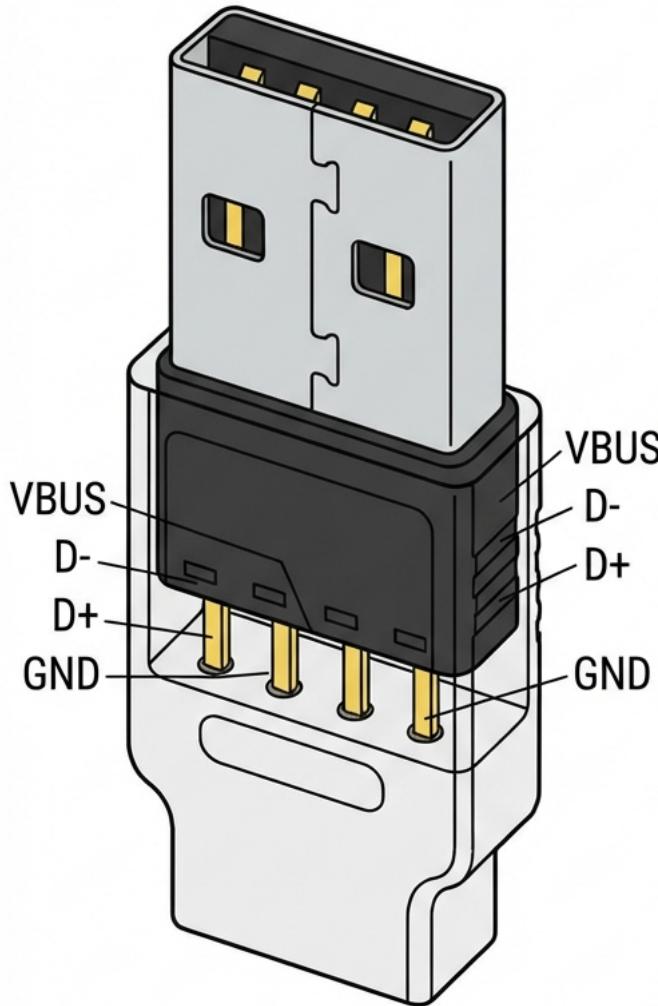
USB			
USB 2.0	500mA	2.5W (5V 0.5A)	
USB 3.0	900mA	4.5W (5V 0.9A)	
USB BC 1.2	1.5A	7.5W (5V 1.5A)	(DCP)
USB 3.1/3.2	3A	15W (5V 3A)	

[!WARNING] Type-A USB PD >15W **Type-C**

3.2.4

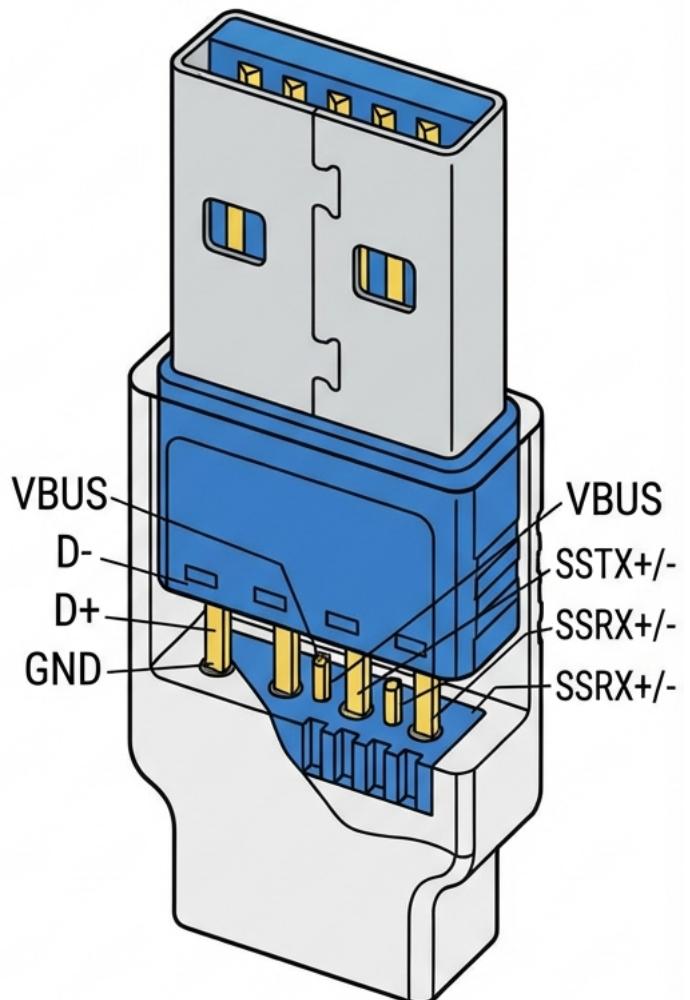


USB 2.0 Type-A



USB 2.0 Type-A

USB 3.0 Type-A (SuperSpeed)



USB 3.0 Type-A (SuperSpeed)

3.3 USB Type-B

Type-B

Type-A

Type-B

3.3.1 Type-B

Standard-B

-
- 8mm × 7mm
- 4 USB 2.0 9 USB 3.0
-

Mini USB Type-B

- Standard-B
- 7mm × 3mm
- 5
- MP3 GPS
- Micro USB

Micro USB Type-B

-
- 7mm × 1.8mm
- 5 USB 2.0
- 2007-2020
- Type-C

Micro USB 3.0 Type-B

- Micro USB 2.0
- 12mm × 1.8mm
- 10 5 USB 2.0 + 5 USB 3.0
- Elements Backup Plus Galaxy Note 3/S5
- Micro USB 2.0

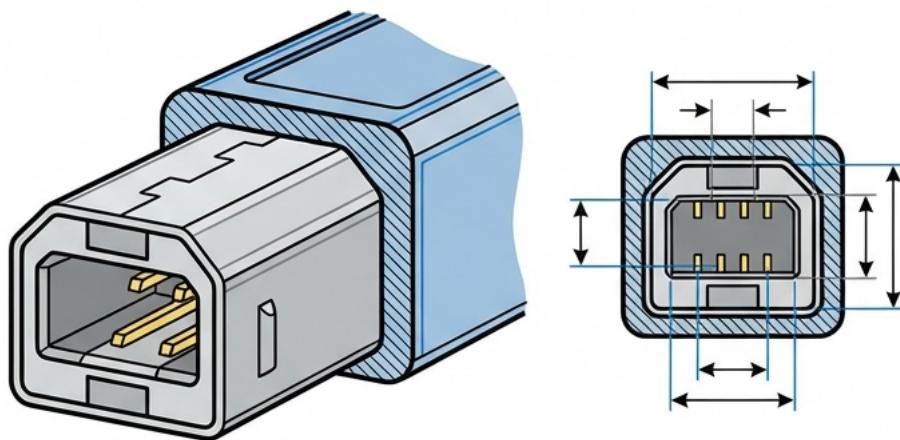
```
graph LR
    A[Standard-B<br/> <br/> ] --- B[Mini-B<br/> <br/>MP3/ ]
    B --- C[Micro-B<br/> <br/> ]
    C --- D[Micro-B 3.0<br/> <br/> ]
```

```
A -->| | B
B -->| | C
C -->| | D
```

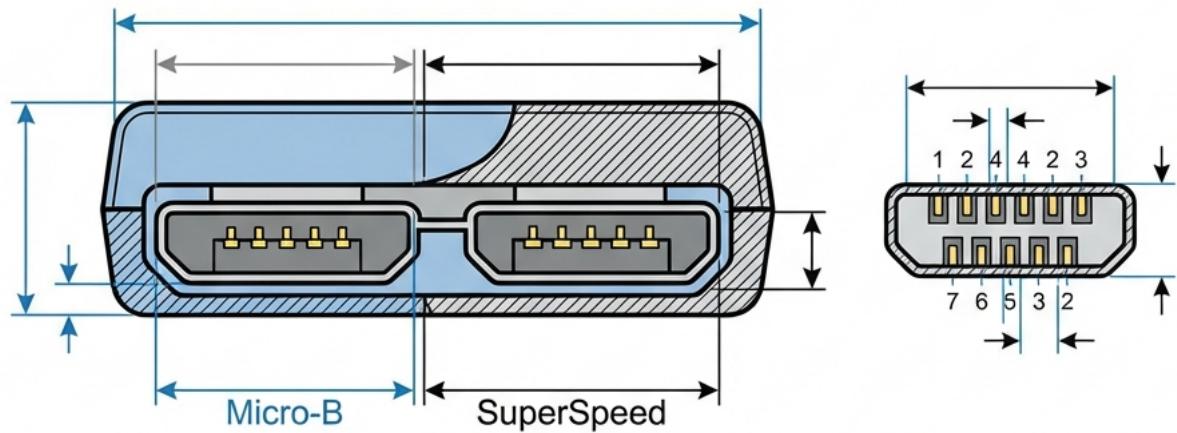
```
style A fill:#e1f5ff
style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#ffe1e1
```

3.3.2 Type-B

- Type-B USB " "
- Standard-B
- **Type-C** Type-C



**USB Standard-B
(Printer)**



**USB Micro-B SuperSpeed
(External HDD)**

3.4 Mini USB & Micro USB

3.4.1 Mini USB

- 2000
- Standard-B
- 5

- **Mini-A**
 - **Mini-B**
 - **Mini-AB** OTG
 - MP3 GPS
 - **2007 Micro USB**
-

3.4.2 Micro USB

Micro USB 2.0 Type-B

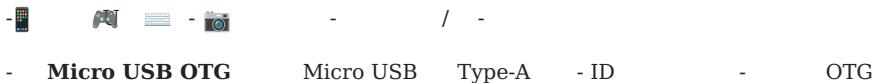
5

1	VBUS	(+5V)
2	D-	
3	D+	
4	ID	OTG
5	GND	

- ID **OTG (On-The-Go)** - ID U - ID - 7mm × 1.8mm
 Mini USB - 10,000

OTG (On-The-Go)

OTG



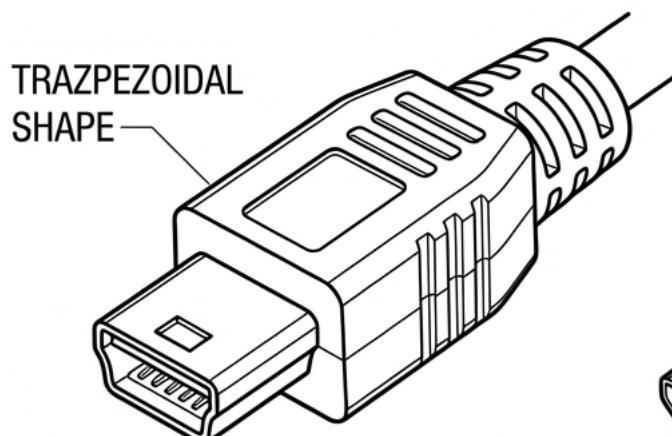
3.4.3 Micro USB

Micro USB

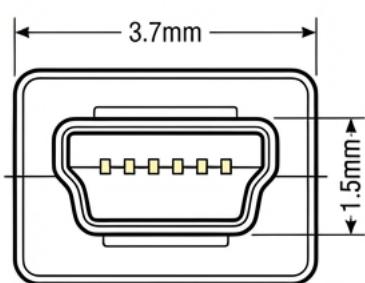
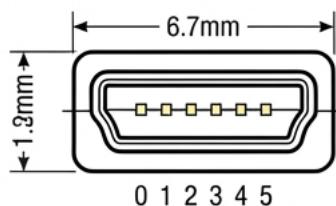
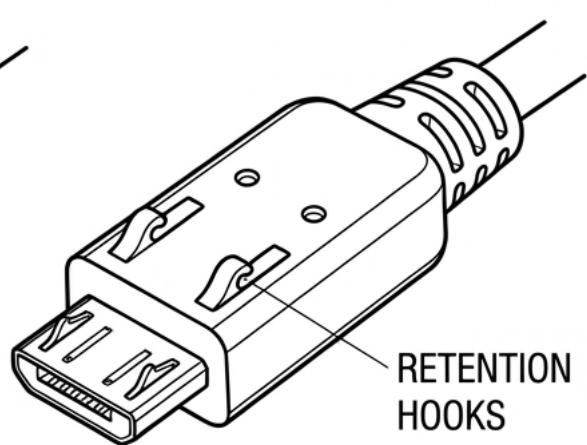
1. - **✗** **✗** **✗** -
2. - 10,000 -
3. - Micro USB **USB 2.0** 480Mbps - 4K - Micro USB 3.0 5Gbps
4. - 7.5W (5V 1.5A, BC 1.2) - 30W+
5. - - Alt Mode

[!WARNING] Micro USB

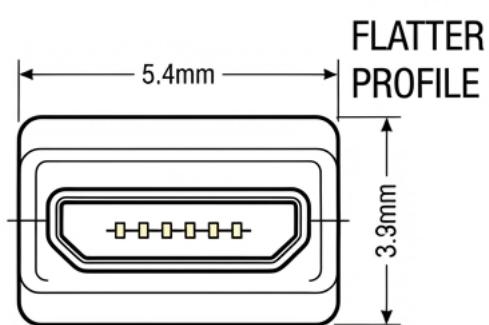
MINI USB



MICRO USB



MINI USB



MICRO USB

3.5 USB Type-C

- 8.4mm × 2.6mm
- 10,000 Micro USB
- 2014

[!IMPORTANT] Type-C

Type-C

USB 2.0

4 (40Gbps)

3.5.1 Type-C

1.
 2. + + +
 3. 240W (USB PD 3.1)
 4. 40Gbps (USB4 / Thunderbolt 4)
 5.
 6.
-

3.5.2 Type-C 24

Type-C **24**

12	A1 GND A2 TX1+ A3 TX1- A4 VBUS A5 CC1 A6 D+ A7 D- A8 SBU1 A9 VBUS A10 RX2- A11 RX2+ A12 GND
12	B12 GND B11 RX1+ B10 RX1- B9 VBUS B8 SBU2 B7 D- B6 D+ B5 CC2 B4 VBUS B3 TX2- B2 TX2+ B1 GND

	8	VBUS (A4, A9, B4, B9) GND (A1, A12, B1, B12)	240W	
USB 2.0	4	D+ (A6, B6) D- (A7, B7)	USB 2.0	480Mbps
USB 3.x/4	8	TX1+/- (A2, A3) RX1+/- (B10, B11) TX2+/- (B2, B3) RX2+/- (A10, A11)	TX/RX	5-40Gbps
	2	CC1 (A5) CC2 (B5)	PD	
	2	SBU1 (A8) SBU2 (B8)	Alt Mode	

[!NOTE] Type-C

3.5.3 CC

CC

CC (Configuration Channel) Type-C

1.

2. CC1 CC2

3. " "

4. **(DRP: Dual-Role Power)**

5. **Source** **Sink**

6. Type-C

7.

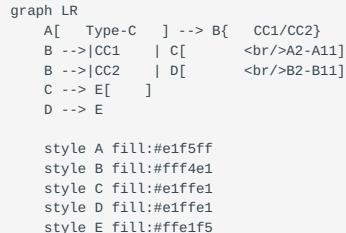
8. Source CC

9. **Default (500mA/900mA) 1.5A 3A**

10. **USB PD**

11.

12. PD Source_Capabilities Request



3.5.4 Alt Mode Type-C

Alternate Mode () Type-C **USB**

Alt Mode

- 1. DisplayPort Alt Mode -** Type-C - - - / - Type-C HDMI/DP - 8K@60Hz DP
2.0 - USB 3.x TX/RX
- 2. Thunderbolt 3/4 Alt Mode -** PCIe DisplayPort USB - 40Gbps - (eGPU) - SSD -
Thunderbolt 3/4 Type-C
- 3. HDMI Alt Mode -** HDMI - Type-C HDMI
- 4. Audio Adapter Accessory Mode -** - Type-C 3.5mm - SBU1/SBU2

Alt Mode



```

style A fill:#e1f5ff
style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#ffe1e1
style E fill:#ffe1ff

```

[!TIP] Type-C Alt Mode " " "DP Alt Mode"

3.5.5 Type-C vs Type-C

Type-C " "

USB 2.0	USB 3.x	Type-C	Thunderbolt 4
480Mbps	5-20Gbps	5-40Gbps	40Gbps
15W	100W	240W (PD 3.1)	100W
✗	✗	✓ (DP Alt Mode)	✓ (DP 2.0)
✗	✗	✗	✓
💰	💰💰	💰💰💰	💰💰💰💰
/PC		/	/Mac

" "
- USB 2.0 Type-C iPhone 15 - USB 3.x PHY - \$1-2 - 480Mbps - Type-C -
DP Mux -
[!WARNING] Type-C - DeX - Type-C - USB
PD

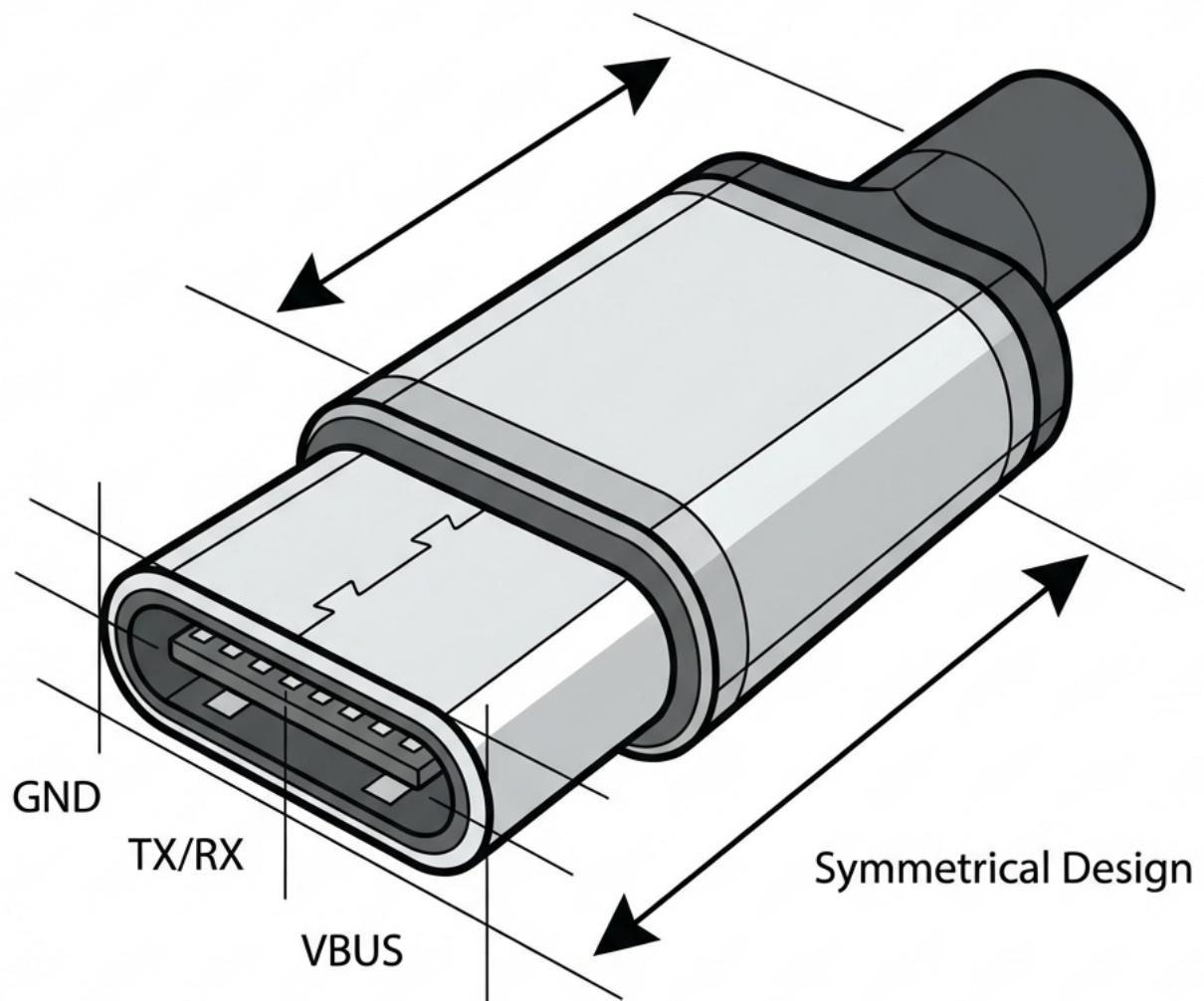
3.5.6 Type-C Thunderbolt

Thunderbolt 3/4 Type-C Type-C ≠ Thunderbolt

USB Type-C	Thunderbolt 3/4
USB2.0~USB4 (480Mbps-40Gbps)	40Gbps
+	+ + +PCIe
USB-IF	Intel
USB	⚡

Thunderbolt

⚡ 1 2 3 4 - Thunderbolt 3/4 "3" 🖥 - MacBook Thunderbolt
- eGPU - 40Gbps - Daisy Chain



3.6 USB

3.6.1

(mm)					
Type-A	12×4.5	4/9		20Gbps (USB 3.2)	15W
Standard-B	8×7	4/9		20Gbps	1,500
Mini USB	7×3	5		480Mbps	2.5W
Micro USB	7×1.8	5		480Mbps	7.5W
Micro USB 3.0	12×1.8	10		5Gbps	7.5W
Type-C	8.4×2.6	24		40Gbps (USB4)	10,000

[!TIP] " " " "

3.7

3.7.1 USB

1. - Type-A - Type-C - Micro USB
2. Type-A - ● USB 3.0/3.1 Gen 1 (5Gbps) / USB 2.0 (480Mbps) - ○ USB 3.2 -
3. - SS (SuperSpeed) USB 3.0 (5Gbps) - SS 10 SS+ USB 3.1 Gen 2 (10Gbps) - SS 20 USB 3.2 (20Gbps) - ⚡ Thunderbolt 3/4 (40Gbps) - USB-IF

Type-C Marker -X ! - USB 2.0 USB 2.0 4✓Mbps - USB 3.x ✓ - E-
 100W ✓5A - Thunderbolt 40Gbps + 100W
 1. SS 5A Thunderbolt 2. USB POWER-Z 3.

3.7.2 FAQ

- Q1:** Type-C - A: Charge-Only Cable " "
- Q2: Type-C Type-A** - A: - Type-A USB 3.2: 20Gbps - Type-A 15W USB PD -
 Type-C Alt Mode
- Q3:** Type-C - A: - " " "DP Alt Mode" - " USB PD" - "USB 3.x/4" -
- Q4: Micro USB OTG** U - A: OTG ID " " U Micro USB ID
- Q5: Type-C** - A: - ⚡ 10 ⚡ ⚡ USB 2.0 - ⚡ ⚡ ⚡ ⚡ 50 USB 3.x + - 100+ +E-
 Marker+USB-IF ⚡ ⚡ ⚡ ⚡ 200+ Thunderbolt 40Gbps
- Q6:** Type-C PD - A: 1. USB PD 2. USB PD 3. 3A 5A E-
 Marker 4.

3.8

3.8.1

USB	USB 3.0	USB 2.0	80Mbps	-	USB 3	USB 2.0	-	Type-C	Type-A	-

3.8.2

Type-C to Type-A	Type-A	15W	
Type-C to HDMI/DP	N/A		
Micro USB to Type-C	USB 2.0 (480Mbps)	7.5W	
Thunderbolt to Type-C	40Gbps	100W	

[!WARNING]

3.8.3

1. - Micro USB Type-A - Type-C
2. - - 24 - -
3. - **Micro USB** - **Type-C** - **Type-A**
4. - - - - >45°C

3.9

3.9.1

Type-C

1	-	- 30W	3A	20	- 67W-100W	E-Marker	5A	40-80	- 100W	EPR	100+	-
Anker	Baseus	UGREEN Apple										
2	-	- USB 2.0	10-20	- /	USB 3.2	30-60	-	Thunderbolt 4	200+	-	- 1	- 1-2
- 3												
3	- Type-C to HDMI/DP	4K@60Hz	-	2	-	Belkin	Cable Matters	Club 3D				
	USB-IF	usb.org	Thunderbolt		-							

3.9.2

- 2× Type-A (USB 3.0) - 1× Type-C (USB 3.1 + PD) - 1× HDMI

- 2× Type-A (1 USB 3.2) - 2× Type-C (1 PD + DP Alt Mode) - 1× HDMI / DP

/ - 1× Type-A (USB 3.2) - 3× Type-C (2 Thunderbolt 4) - 4K - 100W PD

1	/ -	GaN	30-67W	-	PD + PPS	-	Anker	Baseus
2	-	GaN	100-150W	-	2C1A	3C	-	- Anker 747 (150W) Baseus 160W
3	+	-	100W+	-		65W	-	GaN

3.10

	Reversible Plug	Type-C						
Alt Mode	Alternate Mode		Type-C	USB	/			
OTG	On-The-Go			U				
CC	Configuration Channel		Type-C		PD			
SBU	Sideband Use		Type-C		Alt Mode			
DRP	Dual-Role Power		Type-C					
E-Marker	Electronically Marked Cable							
GaN	Gallium Nitride							
eGPU	External Graphics Processing Unit		Thunderbolt					
Daisy Chain			Thunderbolt	6				
PHY	Physical Layer Chip							
DP Mux	DisplayPort Multiplexer		Alt Mode					

3.11

3.11.1

- [USB-IF](#)
- [USB Type-C](#)
- [Thunderbolt](#)

3.11.2

- [USB-IF](#)
-

3.11.3

- **POWER-Z** USB
- **ChargerLAB KT002**
- **USB Device Tree Viewer** USB Windows

• **System Information** Mac USB/Thunderbolt

[!NOTE] USB

USB4 Version 2.0 (80Gbps)

PD

USB-IF

4. 3 USB (USB Transfer Protocols)

USB , USB-IF (USB) , USB

4.1 USB ?

- USB , :
- : U 20 , 200 ?
 - : Type-C , 100 ?
 - :"USB 3.2 Gen 2x2" ?
 - : " " , ?
 - :
 - (20GB):
 - USB 2.0 U : **10**
 - USB 3.2 Gen 2 U : **30**
 - **4K** (100GB):
 - USB 2.0 : **50**
 - USB4 SSD: **30**

USB
[!IMPORTANT] USB ≠ USB Type-C USB 2.0 (480Mbps), USB4(40Gbps)

4.2 USB

```
timeline
title USB
1996 : USB 1.0 : Low Speed 1.5Mbps :
1998 : USB 1.1 : Full Speed 12Mbps :
2000 : USB 2.0 : High Speed 480Mbps : 10+
2008 : USB 3.0 : SuperSpeed 5Gbps : \u003cb>\u003e 10
2013 : : USB 3.0 → USB 3.1 Gen 1 :
2017 : USB 3.1 Gen 2 : 10Gbps :
2017 : USB 3.2 : 20Gbps : Type-C
2019 : : USB 3.x :
2019 : USB4 : Thunderbolt 3 : 40Gbps
2021 : USB4 v2.0 : 80Gbps/120Gbps :
```

4.3 USB

4.3.1 USB 1.0 / 1.1 (1996-2000)

- **Low Speed:** 1.5 Mbps

- :
- : ,

- **Full Speed:** 12 Mbps

- :
- : " ",

4.3.2 USB 2.0 (2000)

- **High Speed: 480 Mbps** (60 MB/s)

• : 30-40 MB/s

• :

• " "

• (iPhone 15)

•

• USB

• :

[!NOTE] USB 2.0 **20+**, , : - () - -

4.4 USB 3.x

USB-IF 2013 2019 , ,

4.4.1 ?

USB-IF : - " , " - " " "

: - - - ,

[!WARNING] USB-IF " " ,

4.4.2

, USB 3.x :

()	(2013)	(2019,)				
USB 3.0	USB 3.1 Gen 1	USB 3.2 Gen 1	USB 3.0 / 5Gbps	5 Gbps	~450 MB/s	8b/10b
N/A	USB 3.1 Gen 2	USB 3.2 Gen 2	USB 3.1 / 10Gbps	10 Gbps	~900 MB/s	128b/10b
N/A	N/A	USB 3.2 Gen 2x2	USB 3.2 / 20Gbps	20 Gbps	~1.8 GB/s	128b/10b

[!TIP] : , : - SS 5Gbps = USB 3.0 () - **SS 10 10Gbps** = USB 3.1 Gen 2 () - **SS 20 20Gbps** = USB 3.2 Gen 2x2 ()

4.4.3

" "

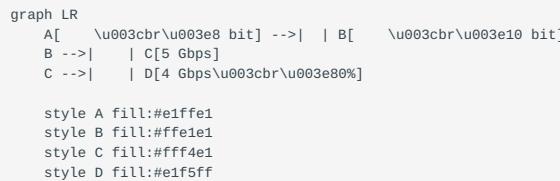
?

USB , 0 1, , : - : - : - : - : -

,

8b/10b (USB 3.0)

- : 8 10
- : $8/10 = \mathbf{80\%}$
- :
- 5 Gbps
- : $5 \times 0.8 = \mathbf{4 \text{ Gbps}}$ (500 MB/s)
- , **450 MB/s**

**128b/132b (USB 3.1/3.2)**

- : 128 132
- : $128/132 = \mathbf{97\%}$
- :
- 10 Gbps
- : $10 \times 0.97 = \mathbf{9.7 \text{ Gbps}}$ (1.2 GB/s)
- , **900 MB/s**

10 Gbps			
8b/10b	80%	8 Gbps	
128b/132b	97%	9.7 Gbps	+21%

[!NOTE] USB 3.1 128b/132b ,

4.4.4 USB 3.2 Gen 2x2

"**2x2**" :

- **2x:** (Dual-Lane)
- **Gen 2:** USB 3.1 Gen 2 (10 Gbps/)
- : $10 \text{ Gbps} \times 2 = \mathbf{20 \text{ Gbps}}$

:

Type-C **4** (TX1/RX1 TX2/RX2): - **USB 3.x:** () - **USB 3.2 Gen 2x2:** ()



```

style A fill:#e1f5ff
style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#e1ffe1
style G fill:#ffe1f5

```

[!IMPORTANT] USB 3.2 Gen 2x2 **Type-C** Type-C Type-A 20 Gbps

4.5 USB4

USB4 Intel **Thunderbolt 3** , , :

4.5.1

- **USB4 Gen 2x2:** 20 Gbps ()
- **USB4 Gen 3x2:** 40 Gbps ()
- : **Type-C**, Type-A

4.5.2

1. (Tunneling Protocol)

USB4 , , :

- **USB 3.2**
- **DisplayPort**
- **PCIe** ()

:

```

graph LR
A[USB4 40Gbps] --> B{ }
B -->| 1: | C[USB 3.2: 40Gbps]
B -->| 2: + | D[DisplayPort: 25Gbps\u003cb\u003eUSB 3.2: 15Gbps]
B -->| 3: | E[PCIe: 32Gbps\u003cb\u003eDisplayPort: 8Gbps]

style A fill:#e1f5ff
style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#ffe1e1
style E fill:#ffe1ff

```

[!TIP] , 4K USB , , 40Gbps

2.

USB4 - **USB 3.2**(, Gen 1/Gen 2/Gen 2) - **USB 2.0** - **Thunderbolt 3**(!) - **Thunderbolt 4**(,)

:

USB4		
USB4 40Gbps	USB4	40 Gbps
USB4 40Gbps	USB 3.2 Gen 2	10 Gbps
USB4 40Gbps	USB 2.0	480 Mbps
USB 3.2 Gen 2	USB4	10 Gbps
Thunderbolt 3	USB4	40 Gbps

3.

USB4 : - 40 Gbps (Gen 3x2) - USB PD - DisplayPort Alt Mode() - Thunderbolt 3 ()
 [!IMPORTANT] USB4 USB 3.x , "USB4" , "

4.5.3 USB4 vs Thunderbolt 3/4

USB4 Thunderbolt, :

	USB4	Thunderbolt 3	Thunderbolt 4
	20/40 Gbps	40 Gbps	40 Gbps
PCIe		(16 Gbps)	(32 Gbps)
		(1×4K)	(2×4K)
PD	7.5W	15W	15W
	2m()	2m()	2m()
	USB-IF	Intel	Intel
USB			+ 4

: - (+):USB4 - ():Thunderbolt 4 - :USB 3.2 Gen 2

4.5.4 USB4 v2.0 (2022)

USB4 2.0 :

- **80 Gbps**()
 - **120 Gbps**(, 120 Gbps, 40 Gbps)
 - :8K
- : 2024 , USB4 2.0 ,
-

4.6

≠ :

4.6.1

: 10GB 4K ()

USB						10GB
USB 2.0	480 Mbps	-	-	35 MB/s	~4 50	★
USB 3.0 (Gen 1)	5 Gbps	80%	4 Gbps	350 MB/s	~30	★★★
USB 3.1 Gen 2	10 Gbps	97%	9.7 Gbps	850 MB/s	~12	★★★
USB 3.2 Gen 2x2	20 Gbps	97%	19.4 Gbps	1.6 GB/s	~6	★★★
USB4 (40Gbps)	40 Gbps	97%	38.8 Gbps	3.2 GB/s	~3	★★★
Thunderbolt 4	40 Gbps	97%	38.8 Gbps	3.5 GB/s	~3	★★★

4.6.2

: 1000 (5GB)

[!NOTE] , , , :

USB			
USB 2.0	35 MB/s	15 MB/s	-57%
USB 3.0	350 MB/s	120 MB/s	-66%
USB 3.1 Gen 2	850 MB/s	250 MB/s	-71%
USB4	3200 MB/s	800 MB/s	-75%

:- (): USB - (): , - : , , (ZIP)

4.6.3

1: (5000 , 20GB)

USB		
USB 2.0	12	✗ ,
USB 3.0	1.5	✓
USB 3.1 Gen 2	40	✓

2: 4K (50GB)

USB		
USB 2.0	25	✗
USB 3.0	2.5	⚠
USB 3.1 Gen 2	1	✓
USB4	15	✓

3: (SSD 100GB)

USB	4K	8K
USB 2.0	✗	✗
USB 3.0	⚠	✗
USB 3.1 Gen 2	✓	⚠
USB4 / Thunderbolt 4	✓	✓

4.7 USB

USB , ?

4.7.1 1:

USB-IF , :

SS	SuperSpeed	USB 3.0 (5 Gbps)
SS 5	SuperSpeed 5Gbps	USB 3.0 (5 Gbps)
SS 10 SS+	SuperSpeed 10Gbps	USB 3.1 Gen 2 (10 Gbps)
SS 20	SuperSpeed 20Gbps	USB 3.2 Gen 2x2 (20 Gbps)
USB 40Gbps USB4 40	USB4	USB4 (40 Gbps)
⚡	Thunderbolt	Thunderbolt 3/4 (40 Gbps)
⚡ 4	Thunderbolt 4	Thunderbolt 4 (40 Gbps)

4.7.2 2: (Type-A)

● /	USB 2.0	480 Mbps
●	USB 3.0 / 3.1 Gen 1	5 Gbps
● (Teal)	USB 3.1 Gen 2	10 Gbps
●	USB 3.2 /	20 Gbps
●		()

[!WARNING]

4.7.3 3:

:

U :

```
: SanDisk Extreme PRO USB 3.2
: USB Type-A
: USB 3.2 Gen 2 (10 Gbps) ←
: 420 MB/s ←
: 380 MB/s
```

:

```
: Samsung T7
: USB Type-C
: USB 3.2 Gen 2 (10 Gbps) ←
: 1050 MB/s ←
: 1000 MB/s
```

[!TIP]

10 Gbps ≈ 1250 MB/s,

1000 MB/s

4.7.4 4:

Windows: - " " → " " - " "**macOS:** - " " → "USB" - " " (" 10 Gb/s"):- **USBTreeView** (Windows): USB - **USB Device Tree Viewer**: USB - **CrystalDiskMark**:

4.8

USB

, , ,

4.8.1



```

style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#ffffacd
style E fill:#ffe4b5
style F fill:#ffe1e1

```

4.8.2

[!IMPORTANT] : 1. (U) 2. (USB) 3. (USB)

:

USB4 SSD (40Gbps)	USB4	USB4	40 Gbps ✓
USB4 SSD (40Gbps)	USB 3.1 Gen 2	USB 3.1	10 Gbps !
USB 3.1 Gen 2 (10Gbps)	USB4	USB 2.0	480 Mbps ✗
USB 3.0 U (5Gbps)	USB4	USB4	5 Gbps !

4.8.3 Type-C

Type-C , :

```

graph LR
A[Type-C \u003cbr\u003e ] --> B[ USB 2.0\u003cbr\u003e480Mbps]
A --> C[USB 3.0\u003cbr\u003e5Gbps]
A --> D[USB 3.1 Gen 2\u003cbr\u003e10Gbps]
A --> E[USB 3.2 Gen 2x2\u003cbr\u003e20Gbps]
A --> F[USB4\u003cbr\u003e40Gbps]
A --> G[Thunderbolt 4\u003cbr\u003e40Gbps]

style A fill:#ffff4e1
style B fill:#ffe1e1
style C fill:#ffffacd
style D fill:#e1ffe1
style E fill:#e1f5ff
style F fill:#e1f5ff
style G fill:#ffe1e1

```

[!CAUTION] Type-C = Type-C USB 2.0, 480Mbps, USB 3.0 Type-A !

4.9

, USB

4.9.1 U

	USB 2.0 / 3.0	¥20-50	DT
	USB 3.1 Gen 1 (5Gbps)	¥50-150	CZ880 DT100 G3
/	USB 3.1 Gen 2 (10Gbps)	¥150-400	BAR Plus
	USB 3.2 Gen 2	¥400+	Extreme PRO

: - ✓ , ✓ - (✓128GB) - - " " ,

4.9.2 / SSD

(1TB)			
	USB 3.0 (5Gbps)	HDD	¥300-500
/	USB 3.1 Gen 2 (10Gbps)	SATA SSD	¥500-800
4K	USB 3.2 Gen 2 (10Gbps)	NVMe SSD	¥800-1500
8K /	USB4 / Thunderbolt 3/4	NVMe SSD	¥1500+

: - **HDD** : , (150 MB/s), - **SATA SSD:** 500 MB/s, - **NVMe SSD:** 1000-3500 MB/s,

[!TIP] USB 3.0 , USB4 ,

4.9.3 USB

	USB 2.0	¥10-30
	USB 3.0	¥30-60
	USB 3.1/3.2	¥60-150 SS 10/20
100W	USB-C 5A E-Marker	¥50-150 E-Marker
/	Thunderbolt 4	¥200-500 ⚡ , 40Gbps

: 1. : - 1 : - 1-2 : () - 3 : , ()

1. :

2. USB-IF : usb.org

3. Thunderbolt ⚡

4. 

5. :

6. ()

7. USB 2.0 USB 3.x

4.10 FAQ

4.10.1 Q1: USB 3.0 U ?

:

1. **USB 2.0**

2. : USB 3.0

3. **USB 2.0**

4. : USB 3.0

5. **U**

6. U USB 3.0, 50-100 MB/s

7. : U

8.

9.

10. :

11.

12. Windows USB 3.0

13. :

4.10.2 Q2: USB 3.2 Gen 2x2 Type-C ?

: , **Type-C**

: - USB 3.2 Gen 2x2 (2 TX/RX) - Type-A 1 TX/RX, - Type-C (24) 2
: - Type-A **USB 3.2 Gen 2**(10 Gbps,) - 20 Gbps Type-C

4.10.3 Q3: USB4 Thunderbolt 4 ? USB4 ?

:

USB4	Thunderbolt 4
20 Gbps(40 Gbps)	40 Gbps
PCIe	(32 Gbps)
	(2×4K 1×8K)
	(6)

: - **USB4** **Thunderbolt 4** : , Thunderbo (PCIe) - **Thunderbolt 4** **USB4** : ,
USB4 Thunderolt - **USB4** : Thunderbolt 3

4.10.4 Q4: USB ?

Windows: 1. " " → " " → " " 2. " " " 3. : - "USB 2.0" = USB 2.0 - "USB 3.0" = USB 3.0 - "USB 4" = USB4

macOS: 1. → → " " → " " 2. "USB" "Thunderbolt" 3. (" 10 Gb/s")
 : - ● : USB ⚡ 0+ - :Thunderbolt - **SS** :

4.10.5 Q5: Type-C , ?

:

1. (Charge-Only Cable)

2. (VBUS/GND),

3. **✓**

4. **✗**

5. :¥10-20

6. **USB 2.0**

7. D+/D-

8. **✓** +

9. **⚠** 480 Mbps

10. :¥20-40

11. **USB 3.x**

12.

13. **✓** +

14. :5-40 Gbps

15. :¥50-200+

: - (SS 5A 10Gbps) - , - , " "

4.10.6 Q6: USB 3.0 USB 2.0, ?

: " " :

1:USB 3.0 → USB 2.0 - **USB 2.0(480 Mbps)** - **⚠**

2:USB 2.0 → USB 3.0 - **USB 2.0(480 Mbps)** - **✓** ,

3:USB 3.0 + USB 2.0 → USB 3.0 - **USB 2.0(480 Mbps)** - **⚠**

[!IMPORTANT] " " " "

4.10.7 Q7: USB 3.2 USB4 ?

:

USB 3.2 Gen 2 (10Gbps) : **✓** (30%) - U **✓** 3.1 **✓** 2 - () -

USB4 (40Gbps) : **✓** **✓** - USB4 Thunderbolt 3/4 - **✓** (4K/**✓**) - (eGPU) -

: - ⚡ **USB 3.1 Gen 2 (10Gbps)** **SSD** , ,

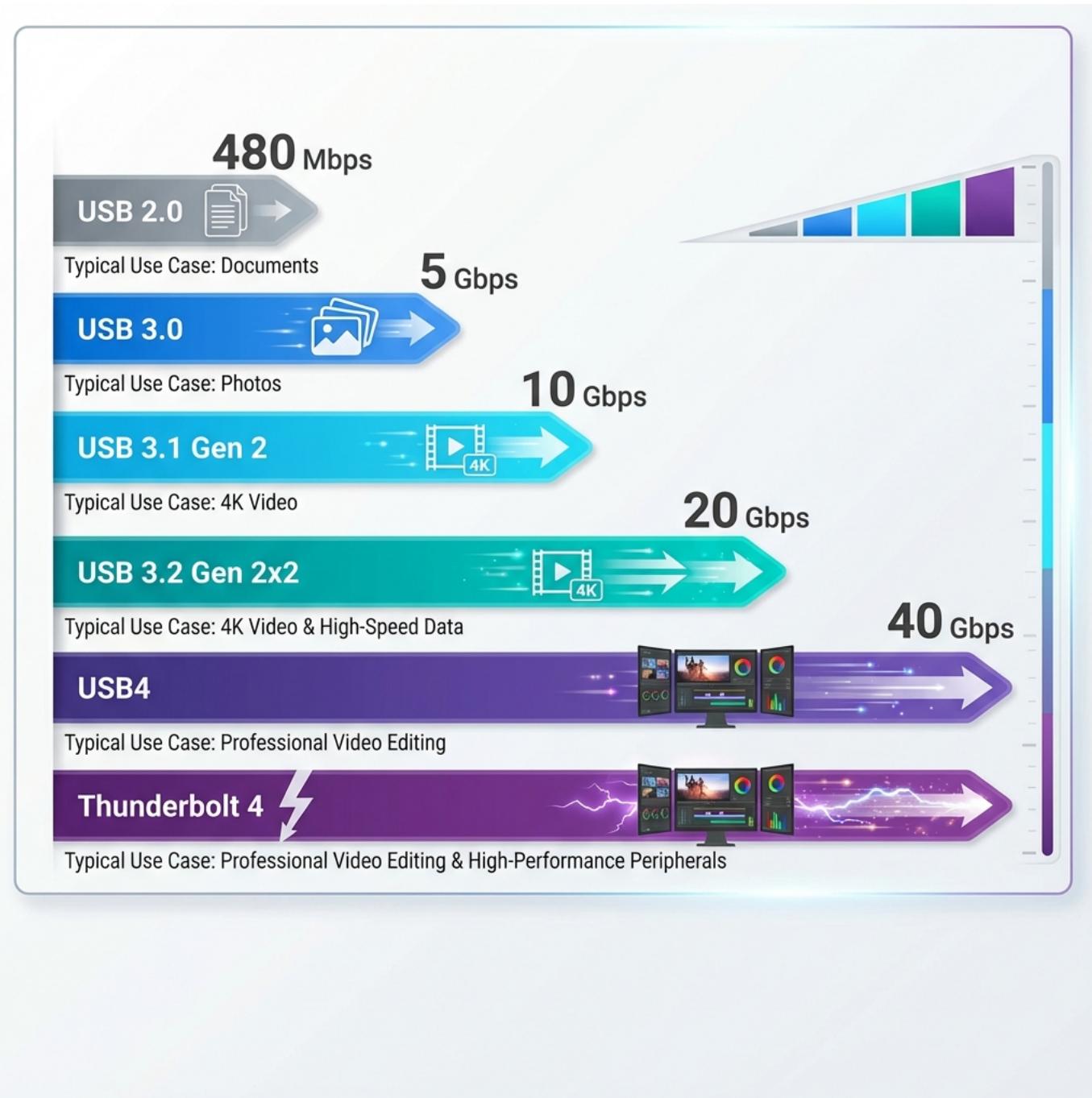
4.11

4.11.1

10GB				
USB 2.0	480 Mbps	~5		★★
USB 3.0 (Gen 1)	5 Gbps	~30		★★★★
USB 3.1 Gen 2	10 Gbps	~12		★★★★★
USB 3.2 Gen 2x2	20 Gbps	~6	4K	★★★★
USB4	40 Gbps	~3		★★★★★
Thunderbolt 4	40 Gbps	~3	+	★★★★★

4.12

- :USB-IF
- :USB-IF
- :CrystalDiskMark ATTO Disk Benchmark
- :
- 2 :USB -
- 4 :Thunderbolt -



5. 4 Thunderbolt () (Thunderbolt Technology)

Thunderbolt **Intel Apple**, " " " PCIe DisplayPort ,

5.1 Thunderbolt?

Thunderbolt , :

- :USB , eGPU
- : (HDMI DP DVI)
- : USB 3.0, 4K/8K
- :
- :

Thunderbolt :

- ⚡ : 40 Gbps(Thunderbolt 3/4) 120 Gbps(Thunderbolt 5)
- 🎮 : PCIe eGPU,
- 🖥️ : 2-4 4K
- ✨ : + + + ,
- 🔗 : 6 ,

[!IMPORTANT] Thunderbolt , MacBook Pro Windows

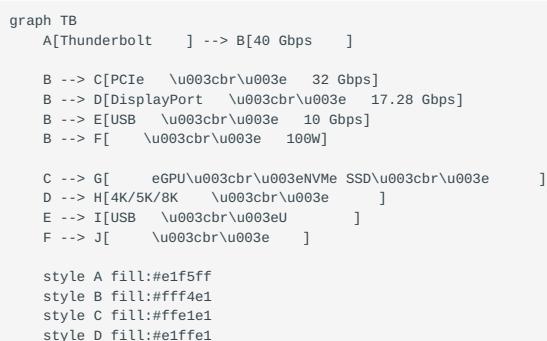
5.2 Thunderbolt

```
timeline
title Thunderbolt
2011 : Thunderbolt 1 : 10 Gbps : Mini DisplayPort \u003cb\u003eApple MacBook Pro
2013 : Thunderbolt 2 : 20 Gbps : \u003cb\u003e 4K
2015 : Thunderbolt 3 : 40 Gbps : \u003cb\u003e USB Type-C
2016 : MacBook Pro : Thunderbolt 3 : "
2020 : Thunderbolt 4 : 40 Gbps( ) : \u003cb\u003e PCIe 32Gbps
2020 : Intel : Thunderbolt 3 USB4 :
2023 : Thunderbolt 5 : 80/120 Gbps : \u003cb\u003e 8K
```

5.3 Thunderbolt

5.3.1 :

Thunderbolt **Protocol Tunneling()** , :



```
style E fill:#ffe1ff
style F fill:#ffffe1
```

:

Thunderbolt

:

	PCIe	DisplayPort	USB	
	32 Gbps	0	8 Gbps	NVMe SSD
4K +	16 Gbps	12 Gbps	8 Gbps	
4K	8 Gbps	25 Gbps	5 Gbps	
eGPU +	28 Gbps	8 Gbps	2 Gbps	/

[!NOTE] Thunderbolt USB USB4 , Thunderbolt

5.4 Thunderbolt

5.4.1

	Thunderbolt 1	Thunderbolt 2	Thunderbolt 3	Thunderbolt 4	Thunderbolt 5
	2011	2013	2015	2020	2023
	10 Gbps	20 Gbps	40 Gbps	40 Gbps	120 Gbps
	Mini DP	Mini DP	Type-C	Type-C	Type-C
PCIe	10 Gbps	20 Gbps	16-32 Gbps	32 Gbps	64 Gbps
DisplayPort	1.1a	1.2	1.2/1.4	1.4	2.1
	1×2K	1×4K	2×4K 1×5K	2×4K	3×4K 2×8K
USB	✗	✗	✓ USB 3.1	✓ USB4	✓ USB4 v2
	N/A	N/A	100W	100W	140W(EPR)
	6	6	6	6	6
	3m()	3m()	0.8m(40G) \\u003cb\\u003e2m())	0.8m() \\u003cb\\u003e2m())	1m(80G) \\u003cb\\u003e3m()
DMA	✗	✗		(VT-d)	
	Mac	Mac/PC			

5.4.2 Thunderbolt 1 & 2:

Thunderbolt 1 (2011)

- : Mini DisplayPort
- : 10 Gbps(, 10 Gbps)
- : Apple MacBook Pro(2011)
- : Intel Light Peak ()

: - , Apple PC - (\$50+) -

Thunderbolt 2 (2013)

- : 20 Gbps(10 Gbps)
 - : 4K@60Hz
 - :
 - , K - PC (Dell HP)
 - Mini DP , - ,
-

5.4.3 Thunderbolt 3:

2015 Thunderbolt 3 , " " " "

1. USB Type-C

: - USB-C , - Type-C - ":" Type-C" USB 3.x Thunderbolt

2. 40 Gbps

- 40 Gbps
- PCIe 3.0 x4(32 Gbps)
- (eGPU)

3. USB 3.1

- USB 3.1 Gen 2(10 Gbps)
- USB-C
- Thunderbolt 3 USB

4.

- 2 4K@60Hz 1 5K@60Hz
- DisplayPort 1.2 HBR2(17.28 Gbps)

5.

- USB PD, 100W(20V 5A)
- Thunderbolt

	40 Gbps()
	USB Type-C
PCIe	Gen 3.0 x4(32 Gbps)
DisplayPort	1.2 HBR2 / 1.4 HBR3
USB	USB 3.1 Gen 2(10 Gbps)
	USB PD 3.0(100W)
	6
	:0.5m(40Gbps)\u003cb\u003e :1-2m(40Gbps)

Thunderbolt 3

Intel :

Alpine Ridge(): - PCIe : 16 Gbps - 4K : - :

Titan Ridge(): - PCIe : **32 Gbps** - 4K : - DisplayPort 1.4: - :

[!WARNING] Thunderbolt 3 "Thunderbolt 3", 16 Gbps PCIe, 32 Gbps Thunderbolt 4

5.4.4 Thunderbolt 4:

Thunderbolt 4 (40 Gbps), ,

1. PCIe **32 Gbps** 💪

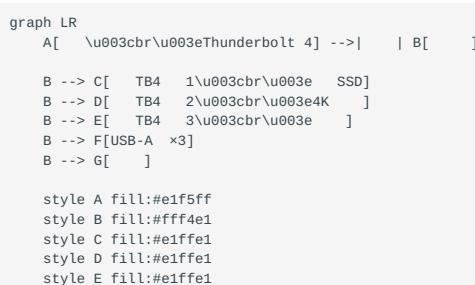
- Thunderbolt 3 16 Gbps
- Thunderbolt 4 32 Gbps
- eGPU SSD

2. 4K

- Thunderbolt 3
- Thunderbolt 4 2×4K@60Hz 1×8K@60Hz

3. (Hub)

- Thunderbolt 3 ()
- Thunderbolt 4 (1 3)



4. DMA

- **Intel VT-d DMA** : Thunderbolt DMA
- Thunderbolt 3 , Thunderbolt 4

5. USB4

- USB4
- USB4 TB4
- TB4 USB4 ()

6.

- : **0.8m**, 40 Gbps
- : **2m**, 40 Gbps
- TB4 USB4 TB3 USB 3.2 USB 2.0
- TB4 100W USB PD

Thunderbolt 4 vs Thunderbolt 3

Thunderbolt 3	Thunderbolt 4
40 Gbps	40 Gbps()
PCIe	32 Gbps
16 Gbps()\u003cb\u003e32 Gbps()	
1-2 4K()	2 4K
DMA	VT-d
USB4	
0.5-2m	0.8m()

[!IMPORTANT] : Thunderbolt 4 , Thunderbolt 4

5.4.5 Thunderbolt 5:

2023 9 , Intel **Thunderbolt 5**,

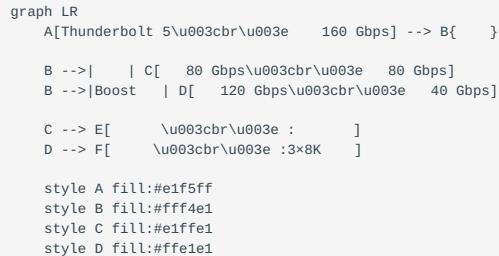
- (): 80 Gbps(80 Gbps)
- (**Bandwidth Boost**): 120 Gbps()+ 40 Gbps()
- **PCIe**: Gen 4.0 x4(64 Gbps)
- **DisplayPort**: 2.1(80 Gbps)
- **USB**: USB4 v2(80 Gbps)
- : USB PD 3.1 EPR(140W, 28V 5A)

Bandwidth Boost

Thunderbolt 5 :

(): - : 80 Gbps - : 80 Gbps - : 160 Gbps

(Boost): - (): **120 Gbps** - (): 40 Gbps - () 8K



1. - 3x 4K@144Hz - 2x 8K@60Hz - 1x 16K ()
2. **eGPU** - PCIe 4.0 x4(64 Gbps) - (10%, Thunderbolt 3/4 15-20%)
3. - PCIe 4.0 NVMe SSD - **8000+ MB/s**

- : 2023 9
- : 2024
- : 2025-2026
- : 2024

[!NOTE] Thunderbolt 5 (2024), , , Thunderbolt 4

5.5 Thunderbolt vs USB4

Thunderbolt USB4,

5.5.1



5.5.2

USB4	Thunderbolt 4
(USB-IF)	Intel
20 Gbps	40 Gbps
40 Gbps	40 Gbps
PCIe	(0-32 Gbps) 32 Gbps
DisplayPort	(2×4K)
USB 3.2	
DMA	VT-d
	Intel
	/

5.5.3

Thunderbolt 4	Thunderbolt 4	✓	(40G + PCIe 32G)
Thunderbolt 4	USB4	✓	USB4 \u003cb\u003e PCIe
Thunderbolt 4	USB 3.2	✓	10-20 Gbps
Thunderbolt 4	Thunderbolt 3	✓	
USB4	Thunderbolt 4	✓	USB4
USB4	USB4	✓	
Thunderbolt 3	Thunderbolt 4	✓	
Thunderbolt 3	USB4	⚠	USB4 TB3

[!IMPORTANT] : - → **Thunderbolt 4** - , PCIe(eGPU) → **USB4** - → **USB** →
USB 3.2

5.5.4 Thunderbolt 4 ?

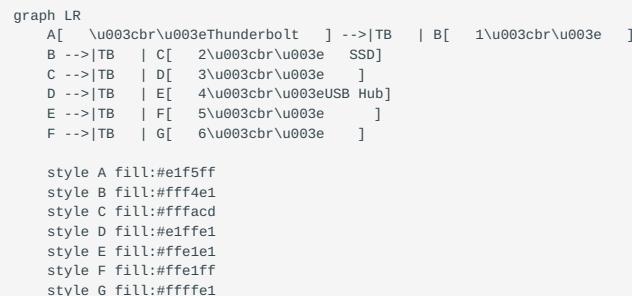
USB4	Thunderbolt 4
, \$5-30	Intel , \$30-50
	Intel
	()
PCB	()

: - USB4 : ¥300-800 - Thunderbolt 4 : ¥1000-3000 - : **2-4**

5.6 Thunderbolt

5.6.1. (Daisy Chain)

6,



: - **Thunderbolt** : 6 - **DisplayPort** : () - **USB** (TB Hub):

:

40 Gbps :

1 4K	32 Gbps
2 4K	12 Gbps
1 eGPU +	eGPU: 28G, : 8G, : 4G

[!WARNING] : - , - , - , - , - Thunderbolt ()

5.6.2. PCIe :eGPU

Thunderbolt **PCIe**

eGPU

```

graph TB
    A[CPU/ ] -->|Thunderbolt 4\u003cbr\u003ePCIe 3.0 x4| B[eGPU ]
    B --> C[GPU\u003cbr\u003e RTX 4070]
    B --> D[\u003cbr\u003e400-750W]
    C --> E[ ]
    E --> F[\u003cbr\u003e4K@144Hz]
    C -.-> G[ ]
    style A fill:#e1f5ff
    style B fill:#ffff4e1
    style C fill:#ffe1e1
    style D fill:#fffffe1
    style E fill:#e1ffe1
    style F fill:#ffe1ff
    style G fill:#ffffacd

```

eGPU

Thunderbolt eGPU :

GPU	eGPU(TB3/4)		
RTX 4060	100%	85-90%	10-15%
RTX 4070	100%	80-85%	15-20%
RTX 4090	100%	70-75%	25-30%

: - PCIe 3.0 x4(32 Gbps) vs PCIe 4.0 x16(256 Gbps) -

[!TIP] **eGPU** : - (GPU,) - **GPU(RTX 4060-4070 Ti),** - Thunderbolt **32 Gbps PCIe**(TB4 TB3) -

5.6.3 3.

Thunderbolt USB PD,

Thunderbolt	
Thunderbolt 3	100W(20V 5A)
Thunderbolt 4	100W(20V 5A)
Thunderbolt 5	140W (28V 5A, EPR)

:

 : -  (65-100W)  (2 ) -  (SSD ) -  (/2.5G) - (DAC) - USB ()

5.7 Thunderbolt**5.7.1 Thunderbolt ?**

1.

Thunderbolt 3/4/5: -  (Thunderbolt Logo) - :"3" "4" "5" - "40" "USB4"

: - ⚡ = Thunderbolt 3 - ⚡ 4 = Thunderbolt 4 - ⚡ 5 = Thunderbolt 5

[!WARNING]

Thunderbolt!

2.

macOS: 1. Apple → " → " 2. "Thunderbolt" "USB" 3.

Windows: 1. " → " → " 2. " 3. "Thunderbolt(TM) Controller"

Linux:

```
lspci | grep Thunderbolt
sudo dmesg | grep thunderbolt
```

3. (Type-C)

Thunderbolt 3/4/5 Type-C, ⚡ : - - (+ +) - MacBook Pro Thunderbolt

5.7.2 Thunderbolt

TB3	40 Gbps	≤0.5m	¥80-200	,
TB3	40 Gbps	1-2m	¥200-500	,
TB4	40 Gbps	≤0.8m	¥150-300	,
TB4	40 Gbps	2m	¥300-800	

: - ✓ Intel Thunderbolt Certified - ✓ 50 (USB PD 5A✓) - SS 40(40 Gbps)

(¥800-1500): - 1 TB4 - 2-3 USB-A - 1 HDMI 2.0(4K@60Hz) - - 65W - : CalDigit Belkin Anker

(¥1500-2500): - 1 TB4 - 2-3 TB4 - USB-A/C - HDMI DP(4K) - 2.5G - 85-96W - SD - : OWC CalDigit TS4

(¥2500-4000+): - 3 TB4 - DisplayPort 1.4 - 10G - 96-100W - DAC - : OWC Thunderbolt Dock CalDigit TS4

[!TIP] : 1. : () 2. **TB** : TB (SSD) 3. : 4. : 2.5G
10G 5. : Intel ,

(1TB)			
TB3 HDD	200 MB/s	¥600-1000	LaCie G-Tech
TB3 SATA SSD	500 MB/s	¥800-1500	Samsung X5
TB3 NVMe SSD	1500-2800 MB/s	¥1500-3000	Samsung X5 OWC Envoy Pro
TB4 NVMe SSD	2000-3000 MB/s	¥2000-4000	OWC Envoy Pro Acasis

eGPU

		PCIe		
Razer Core X	650W	x16(TB@x4)	4×USB,	¥2000-2800
Sonnet eGFX Breakaway Box	550W	x16		¥1500-2200
AORUS Gaming Box	450W	x16	3×USB	¥2500-3500(GPU)

: - ≥ GPU TDP + 100W - GPU - macOS GPU (AMD)

5.8 Thunderbolt**5.8.1 1:**

: - MacBook Pro 16"(M3 Max,Thunderbolt 4) - OWC Thunderbolt Dock(3×TB4) - 2× 4K () - 4TB NVMe SSD(TB4,) - 8TB HDD(,USB)

: - : , - : , - 4K :2500 MB/s,100GB 40

5.8.2 2: + eGPU

: - (Thunderbolt 4) - Razer Core X eGPU Box - RTX 4070 - 2K@165Hz

: - : (1.3kg) - : eGPU, 5-8 - : +

: - 2077 :2K 80-100 FPS - :2K 120 FPS - : 15%()

5.8.3 3:

: - MacBook Pro 14" - Universal Audio Apollo Twin() - MIDI (USB) -

: - : <2ms(USB 5-10ms) - DSP :Apollo DSP, CPU - : 10+

5.8.4 4:

: - MacBook Pro 16" - OWC Envoy Pro(2TB NVMe SSD,) - SD (USB-C) - CalDigit TS4 ()

: 1. (SD) 2. SSD(500+ MB/s) 3. SSD (Lightroom Photoshop) 4. : , NAS

: - 64GB RAW : 2 (USB 3.0 10+) - PSD : 2500 MB/s,

5.9 FAQ

5.9.1 Q1: Thunderbolt USB-C ?

:

- **USB-C:** (), Type-C :
- USB 2.0(480 Mbps)
- USB 3.2(10-20 Gbps)
- USB4(20-40 Gbps)
- Thunderbolt 3/4/5(40-120 Gbps)
- **Thunderbolt:** , Thunderbolt 3/4/5 Type-C , Type-C ≠ Thunderbolt

: 

5.9.2 Q2: Type-C , Thunderbolt ?

: , Type-C

:

Thunderbolt			
Thunderbolt 4	TB4/TB3		
Thunderbolt 3	TB4/TB3		(TB3)
USB4	TB4/TB3		PCIe
USB 3.2	TB		USB , TB
USB 2.0 Type-C	TB		480 Mbps,

[!IMPORTANT] eGPU Thunderbolt USB-C

5.9.3 Q3: Thunderbolt , ?

:

: -   - U  (U) - (<0.5m)

: -  40 Gbps  - eGP   - 100W ( A E-Marker) - (>1m)

[!WARNING] Thunderbolt , ¥20 ¥20000 !

5.9.4 Q4: Mac Windows PC Thunderbolt ?

Mac	Windows PC
Thunderbolt	MacBook Pro/Air /
Apple	
eGPU	macOS (AMD) Windows (NVIDIA/AMD)
	BIOS

: - Mac : eGPU AMD (RX 6000/7000) - Windows : eGPU NVIDIA(RTX ,)

5.9.5 Q5: Thunderbolt ?, ?

:

1. - Thunderbolt() - Thunderbolt

2. - Thunderbolt -

3. - Windows: Intel Thunderbolt - Mac: macOS - (eGPU)

4. BIOS/ - Windows PC: BIOS, Thunderbolt - "Thunderbolt Boot Support" - Mac: → → Thunderbolt

5. - (Thunderbolt) - eGPU

6. SMC/NVRAM(Mac)

```
SMC: → Shift+Control+Option+ 10
NVRAM: Command+Option+P+R,
```

5.9.6 Q6: Thunderbolt ?, ?

:

1. DMA (Direct Memory Access)

- Thunderbolt
-
- :
- Thunderbolt 4(VT-d DMA)
- Windows: "Kernel DMA Protection"
- Mac: → → Thunderbolt

2. Thunderspy

- 2020
- Thunderbolt 1/2/3(2019 -)
- :
- Thunderbolt 4(-)
- :
- Secure Boot
- :
- Thunderbolt
- Thunderbolt
-
- (FileVault BitLocker)
- Thunderbolt 4

5.9.7 Q7: Thunderbolt 5 ? ?

Thunderbolt 5 (2024 -):

- : 2023 9
 - : 2024
 - : 2024 -2025
 - : 2025-2026
- : - (50-100%) - 2026
- :

Thunderbolt 4 : 1-2) - Thunderbolt 4 40 Gbps - (TB5)

Thunderbolt 5 : 3 4K 2 8K - NVMe SSD - , - 1-2

[!TIP] , Thunderbolt 4 2024-2025 TB5 120 Gbps " "

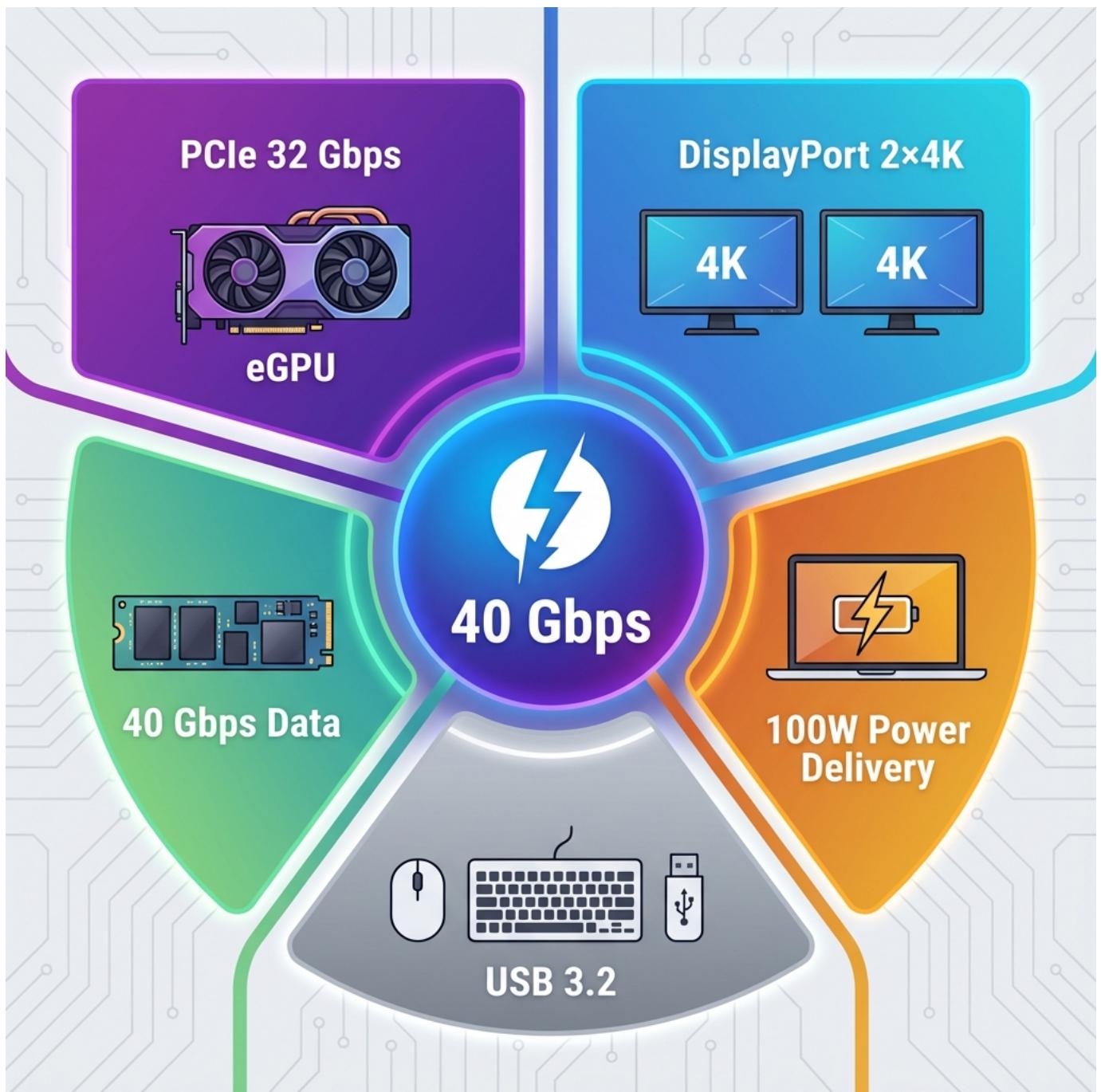
5.10

5.10.1 Thunderbolt

	TB1	TB2	TB3	TB4	TB5
	10 Gbps	20 Gbps	40 Gbps	40 Gbps	120 Gbps
	Mini DP	Mini DP	Type-C	Type-C	Type-C
PCIe	10G	20G	16-32G	32G	64G
	1×2K	1×4K	2×4K	2×4K	3×4K/2×8K
USB	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	USB 3.1	USB4	USB4 v2
	-	-	100W	100W	140W

5.11

- : Thunderbolt Technology
- : Thunderbolt Certified Products
- : Intel Thunderbolt Specifications
- :
- 2 :USB - Type-C
- 3 :USB - USB4 vs Thunderbolt
- 5 : - USB PD Thunderbolt



6. 5 (Charging & Power Delivery)

USB 2.5W (5V 0.5A) 240W

6.1

6.1.1 USB BC 1.2 (Battery Charging)

USB BC 1.2 USB-IF 2010

- 7.5W (5V 1.5A)
- D+/D-
-
- **SDP (Standard Downstream Port)** USB 500mA
- **CDP (Charging Downstream Port)** + 1.5A
- **DCP (Dedicated Charging Port)** 1.5A
-

6.2

6.2.1

2010

- **USB 2.0** USB **2.5W** (5V 0.5A) 4-6
- **USB BC 1.2** 7.5W (5V 1.5A)
- USB PD 1.0 2012 2016 PD 3.0
-
- " 5 2 "
-
- 2013-2016 USB PD

OPPO " "

[!IMPORTANT]

6.2.2

```
timeline
  title
  2010 : USB BC 1.2 (7.5W) :
  2012 : USB PD 1.0 :    PD    <br>
  2013 :    QC 1.0 (10W) :
  2014 :    QC 2.0 (18W) :
  : OPPO VOOC (20W) :
  2015 :    FCP (18W) :
  :        PE+ : MTK
  2016 :    QC 3.0 : 200mV
  :        SCP (22.5W) :    <br>
  : USB PD 3.0 :
  : vivo      (22.5W)
  2017 :    PE 3.0 (30W)
  :        QC 4 :    USB PD
  2018 : OPPO SuperVOOC (50W) :
  :        (27W)
  :        QC 4+
```

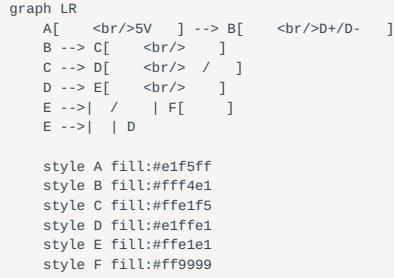
```

2019 : OPPO SuperVOOC 2.0 (65W)
    : SCP 2.0 (40W)
2020 : QC 5 (100W+) : PD
    : (120W)
2021 : OPPO 125W/240W :
    : (210W)
    : vivo (200W)
2023 : Type-C :

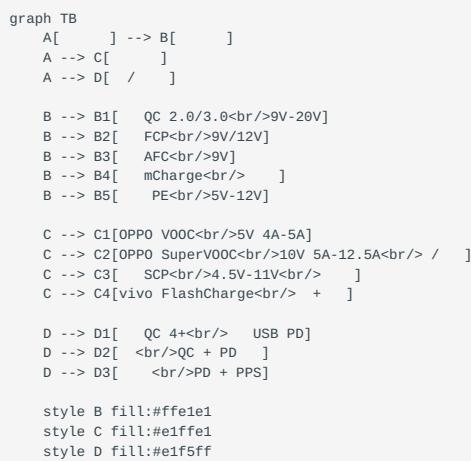
```

6.2.3

Handshake Protocol



1. 5V
 2. D+/D-
 - 3.
 4. /
 - 5.
- [!NOTE] D+/D- USB " " "



6.2.4 Quick Charge (QC)

Quick Charge

Android

QC 1.0 (2013)

- 10W (5V 2A)

-
-

QC 2.0 (2014)

QC 2.0

- 18W
-
- Class A: 5V 9V 12V
- Class B: 5V 9V 12V 20V
- 3A
- D+/D-
- 5V D+ = D- = 0.6V
- 9V D+ = 3.3V, D- = 0.6V
- 12V D+ = 0.6V, D- = 0.6V
- 20V D+ = 3.3V, D- = 3.3V Class B

QC 3.0 (2016)

QC 3.0

- 18W 22W
- 3.6V - 20V
- **200mV** QC 2.0
-
-
- **38%** QC 2.0
-
- QC 2.0

QC 4 / QC 4+ (2017-2018)

QC 4/4+ USB PD

- 28W (QC 4) 100W (QC 4+)
-
- **USB PD 3.0** PD
- **PPS (Programmable Power Supply)**
- **INOV (Intelligent Negotiation for Optimum Voltage)**
- QC USB PD
-

QC 5 (2020)

- **100W+**
- 98%

• USB PD QC	[!IMPORTANT] QC 4	USB PD	QC 4+	PD	iPhone MacBook
-----------------------	-------------------	--------	-------	----	------------------

6.2.5 OPPO VOOC

OPPO VOOC

VOOC (2014)

- 20W
- / **5V 4A**
-
- QC 5V 4A-5A
- 7 **Micro-USB** 5 2
-
- **MCU ()**
-
-
-
-
-

SuperVOOC (2018)

SuperVOOC

- 50W
- / **10V 5A**
-
- 2000mAh
- 10V 5V
- 5V 10V 5A
-

SuperVOOC 2.0 (2019-2020)

- 65W
- / **10V 6.5A**
- OPPO Find X Reno

125W / 240W (2021-)

OPPO	- 125W 10V 12.5A	- 240W 24V 10A	OPPO	Type-C	VOOC
------	-------------------------	-----------------------	------	--------	------

6.2.6 FCP / SCP

FCP (Fast Charge Protocol, 2015)

- 18W
- 9V / 12V
- 2A
- D+/D-
-

SCP (SuperCharge Protocol, 2016)

SCP	VOOC	SCP	FCP	FCP	FCP	SCP
•						
• SCP 1.0 22.5W (5V 4.5A 4.5V 5A)						
• SCP 2.0 40W (10V 4A)						
• SCP 3.0 66W (11V 6A)						
•						
•						
•						
•						
• FCP						
[!NOTE] FCP SCP		SCP	FCP	FCP	FCP	SCP

6.2.7 Pump Express (PE / PE+)**Pump Express Plus (PE+, 2015)**

- 18-24W
- 5V - 12V
-
- D+/D-
-
-
- QC

Pump Express 3.0 (PE 3.0, 2017)

- 30W
- 3V - 6V
- **USB Type-C** Type-C
- 20 70%

USB PD PE

6.2.8 vivo FlashCharge

vivo " "

(2016)

- 22.5W
- / 9V 2.5A 5V 4.5A
-

FlashCharge 2.0

- 44W 55W 66W 120W 200W
-
- vivo

6.2.9

USB PD

(Mi Turbo Charge)

QC 3.0 (2016-2017)	-	18W (9V 2A / 12V 1.5A)	-	QC 3.0	-	5	Note 2	-		
27W (2018)	-	27W (9V 3A)	-	QC 4/QC 4+	USB PD	-	MIX 2S	8	-	QC PD

(2019-2020)

33W	-	33W (11V 3A)	-	-	-	-	-	-	9 Pro Redmi K20 Pro
50W	-	50W (10V 5A)	-	+ USB PD	-	25W	-	10 Ultra	
67W	-	67W (11V 6.1A 20V 3.35A)	-	-	11V 6.1A	-	USB PD	20V 3.35A	-
		2250mAh	-	33.5W	-	11	Redmi K40 Pro		

(2021-)

120W	-	120W (20V 6A 12V 10A)	-	-	12V 10A	-	PD	20V 6A	-	-	+	-		
2500mAh	-	MTW	-	15	4500mAh	-	11 Pro/Ultra	12 Pro						
210W	(2023)	-	210W (20V 10.5A)	-	-	100W	+	-	15C	2-3C	-	MTW	-	4
50% 9			4900mAh	-	Redmi Note 12									

- **USB PD** iPhone MacBook - **QC** QC 3.0/4+

/

```
graph LR
    A["<br/>120W"] --> B[USB-C]
    B --> C["1<br/>60W"]
    B --> D["2<br/>60W"]
    C --> E["1<br/>2500mAh"]
    D --> F["2<br/>2500mAh"]

    style A fill:#fffe1e1
    style C fill:#e1f5ff
    style D fill:#e1f5ff
    style E fill:#e1ffe1
    style F fill:#e1ffe1
```

- 34 -

80%

		PD	QC
120W	120W	65W PD	18W QC 3.0
67W	67W	45W PD	18W QC 3.0
PD	27W-45W PD	PD	QC

[!TIP]

[!NOTE] 67W

USB PD

6.2.10 (mCharge)

- 18W 24W 36W
- QC
-

6.2.11 AFC (Adaptive Fast Charging)

- 15W 18W
- 9V
- 1.67A (15W) 2A (18W)
- D+/D-
- QC 2.0 9V

[!TIP]

USB PD + PPS AFC

6.3

QC 2.0/3.0	18W		
QC 4+	100W	USB PD	PD
VOOC/SuperVOOC	20-240W		OPPO/OnePlus/realme
FCP	18W	/	
SCP	22.5-66W	/	
PE/PE+	18-24W		MTK
AFC	15-18W		QC

6.4

6.4.1

-
- 5V 1A/2A
-
- QC 2.0/3.0 9V
- QC + FCP

6.4.2

- **VOOC**

-
-

6.4.3 USB PD

[!IMPORTANT] USB PD 3.0 **PPS** Type-C
- QC 4+ USB PD - PD - PD + PPS - **OPPO/** PD

6.4.4

- 1.
- 2.
3. **USB PD** USB PD
- 4.

6.5 USB PD (Power Delivery)

USB PD **USB-IF** Type-C

6.5.1 USB PD

- ✗
- ✗
- ✗
- ✗

USB PD

6.5.2 USB PD

D+/D- USB PD **CC** Configuration Channel

CC

Type-C CC CC1 CC2

1. Type-C
2. Source Sink
3. CC

4. PD**PD**

```
sequenceDiagram
    participant C as <br/>(Source)
    participant D as <br/>(Sink)

    Note over C,D:
    C->>D: 1. (CC )
    C->>D: 2. 5V

    Note over C,D:
    C->>D: 3. Source_Capabilities<br/>()
    Note right of D: : 5V/3A, 9V/3A,<br/>15V/3A, 20V/5A

    D->>C: 4. Request<br/>( 20V 3A)

    C->>D: 5. Accept<br/>()

    Note over C,D:
    C->>D: 6. PS_RDY<br/>()
    C->>D: 7. 20V 3A

    Note over C,D:
    D->>C: Request<br/>
```

1. Type-C CC
2. 5V
3. Source_Capabilities /
4. Request
5. Accept Reject
6. PS_RDY Power Supply Ready
- 7.

[!IMPORTANT] USB PD " " D+/D- " " PD

6.5.3 PD

USB PD CC

Source_Capabilities	Source → Sink	
Request	Sink → Source	
Accept	Source → Sink	
Reject	Source → Sink	
PS_RDY	Source → Sink	
Get_Sink_Cap	Source → Sink	
Soft_Reset	Both	PD
Hard_Reset	Both	5V

6.5.4

PD 2.0 / 3.0 (2016-2018)

- **100W** (20V 5A)
-
- 5V
- 9V 12V 15V 20V
- 5A E-Marker
-
- **45W** 5V/3A, 9V/3A, 15V/3A, 20V/2.25A - **65W** 5V/3A, 9V/3A, 15V/3A, 20V/3.25A - **100W** 5V/3A, 9V/3A, 15V/3A, 20V/5A

PD 3.1 (2021)

- **240W** (48V 5A)
- **EPR (Extended Power Range)**
- 28V 36V **48V**
-
- **EPR**

6.5.5 PPS (Programmable Power Supply)

PPS **USB PD 3.0**

PPS

PD 5V 9V 15V 20V - 9V 4.2V - 9V → 4.2V -

PPS

- 3.3V - 21V PD 3.0 PPS
- **20mV** 0.02V
-

```

graph LR
    A["PD<br/>9V"] -->| | B["4.2V"]
    C["PPS<br/>4.2V"] -->| | D["4.2V"]

style A fill:#ffe1e1
style B fill:#ffff4e1
style C fill:#e1ffe1
style D fill:#e1ffe1

Note1[<br/>]
Note2[<br/>]

```

PPS

- ⚡
- 🌡
- 💡 5-10%
- 📱

PPS

PPS

PPS		
0-30%	3.6V	3.8V
30-70%	3.9V	4.1V
70-90%	4.1V	4.3V
90-100%	4.3V	4.4V

[!NOTE] " 2.0" "PD" PPS iPhone 15 Pro PPS

6.5.6 USB PD vs

USB PD		
✓	USB-IF	✗
✓		✗
CC	D+/D-	/
" "		
240W (PD 3.1)	240W (OPPO)	
✓ PPS 20mV		QC 3.0 200mV
✓		
✓	✗	
✓		⚠

PD

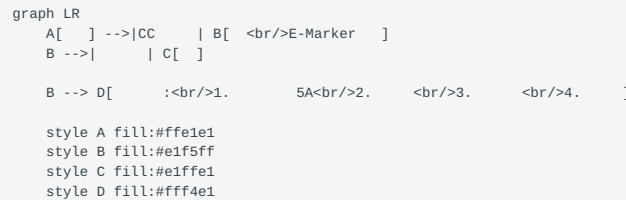
1. 2024 USB-C
 2. PPS PD
 3. PD
 - 4.
- [!IMPORTANT] OPPO **USB PD** " "

6.6 (E-Marker)

Type-C

- **3A** C-to-C 60W (20V 3A)
- **5A** **E-Marker** " 5A " 100W (20V 5A)
- **EPR** PD 3.1 240W

6.6.1 E-Marker



[!WARNING] 3A 100W 60W

6.7

6.7.1 1

66W (SCP)	Mate 40 Pro	66W	65W	SCP	
66W (SCP)	11	66W	27W	USB PD	PD
66W (SCP)	iPhone 14 Pro	66W	27W	USB PD	PD iPhone
OPPO 65W (VOOC)	OPPO Find X5 Pro	65W	65W	SuperVOOC	
OPPO 65W (VOOC)	11	65W	10W		
OPPO 65W (VOOC)	iPhone 14 Pro	65W	0W		VOOC PD
120W	12 Pro	120W	120W		
120W	iPhone 14 Pro	120W	27W	USB PD	PD iPhone
120W	MacBook Pro 14	120W	96W	USB PD	PD
140W (PD)	MacBook Pro 16	140W	140W	USB PD 3.1	
140W (PD)	12 Pro	140W	67W	USB PD	PD
140W (PD)	Mate 40 Pro	140W	27W	USB PD	PD SCP

USB PD - + PD - SCP PD - **OPPO VOOC**

6.7.2 2

11 Pro (67W) + 67W

0-50%				
6A	67W	15		
5A E-Marker	60W	17		
3A	18W	45		
	10W	70		
1	67W	15		
3	25W	35		

- - - - >60W 5A/6A

6.7.3 3

1	PD	-	Anker Switch	-	100W / 140W USB-C PD	-	USB PD 3.0/3.1 + PPS + QC 4+ -
2	GaN	-	Anker - Anker 747 (150W)	-	100W / 120W 100W (C1) / 100W (C2)	-	2C1A / 3C1A 100W + 50W - 65W + 45W + 40W
3		-	Baseus Ugreen	-	200W+	4-6	-
[!TIP]	GaN				100W GaN		1/3

6.8

6.8.1

USB BC 1.2		USB PD
(OVP)	5-10V	+
(OCP)	MCU	CC
(OTP)	/	
(SCP)		
	BMS +	BMS + PD
		E-Marker
		PS_RDY
		Role Swap

6.8.2

- 1.
2. USB-IF
3. USB-IF
4. " "
- 5.
6. /
7. >50°C
8. VOOC/SuperVOOC
- 9.
10. 100%
11. 80-90% " "
- 12.
13. <0°C >40°C
- 14.
- 15.

16.

17.

6.9

USB-IF	USB Implementers Forum	USB	USB
D+/D-	Data Plus / Data Minus	USB	
CC	Configuration Channel	Type-C	PD
E-Marker	Electronically Marked Cable		
MCU	Microcontroller Unit		
BMS	Battery Management System		
	Direct Charging		
	Dual-Cell Battery		
	Multi-Tab		
	Handshake Protocol		
GaN	Gallium Nitride		
PPS	Programmable Power Supply	PD 3.0	20mV
EPR	Extended Power Range	PD 3.1	28V-48V 240W
OVP	Over Voltage Protection		
OCP	Over Current Protection		
OTP	Over Temperature Protection		
SCP	Short Circuit Protection		SuperCharge Protocol
C-to-C	USB-C to USB-C	Type-C	Type-C
A-to-C	USB-A to USB-C	USB-A	Type-C

6.10

6.10.1

- USB Power Delivery Specification (USB-IF)
- USB Type-C® Cable and Connector Specification
- Qualcomm Quick Charge

6.10.2

- **POWER-Z** USB
- **ChargerLAB KT002** PD
-

6.10.3

- USB-IF
-

[!NOTE]

2023

USB-IF

7. 6

(FAQ & Common Misconceptions)

7.1



-
-
-
- Thunderbolt
-
-
-
-

7.2

7.2.1 Q1: Type-C ?

A: !

Type-C (), :

		5-15W		¥10-20
USB 2.0	480 Mbps	15W		¥20-40
USB 3.2 Gen 1	5 Gbps	60W		¥40-80
USB 3.2 Gen 2	10 Gbps	100W		¥80-150 +
USB-C	10-20 Gbps	100W		¥100-200
Thunderbolt 4	40 Gbps	100W		¥200-500

: 1. (SS 5A) 2. 3. USB 4. ,

[!WARNING] !¥10 ¥500 , "Type-C"

7.2.2 Q2: Type-C USB-C ?

A: , : - **Type-C:** USB-IF - **USB-C:**

: 24 USB

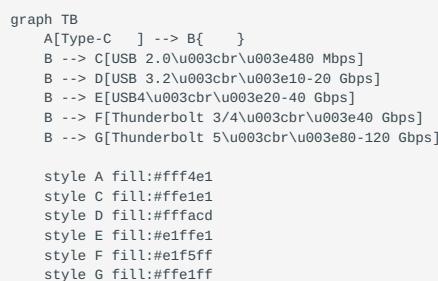
- : Type-C/USB-C ≠ ≠
- Type-C
 - (USB 2.0 USB 3.x USB4 Thunderbolt)
-

7.2.3 Q3: Thunderbolt USB-C ?

A:

- **USB-C/Type-C:** ()
- **Thunderbolt:** ()

: - Thunderbolt 3/4/5 Type-C - Type-C Thunderbolt - Thunderbolt - USB-C



: ⚡

7.2.4 Q4: Type-C ?

:

1. - Thunderbolt, USB-C - :
 2. - () - - - :
 3. - **Windows:** USB/Thunderbolt - **Mac:** - - - :
 4. - (eGPU) - - - :
 5. - Thunderbolt - - - , Thunderbolt
- :
-

7.2.5 Q5: USB Type-A ?

A: ,

Type-A : - ✓ : ✓, - : ▲U - - - : (>15W) (>20Gbps)
 : - : Type-C(Type-C) - - : Type-A() - - : Type-C, - - : Type-A ,
 [!NOTE] 2024 Type-C (),

7.2.6 Q6: Mini USB Micro USB ? ?

A: , Type-C

Mini USB	Micro USB	
2000	2007	-
(7×3mm)	(7×1.8mm)	-
5,000	10,000	-
480 Mbps (USB 2.0)	480 Mbps (USB 2.0)	-
MP3		-
		Type-C

: ! Type-C

7.3

7.3.1 Q7: USB 3.0 U ?

:

1. USB 2.0

30-40 MB/s	(USB 2.0)	(USB 3.0)
30-40 MB/s	USB 2.0	USB 3.0

2. U - : USB 3.0 , 50-100 MB/s - : U - : U ()

3. - : , - : - : (ZIP/RAR),

4. - : " " - : USB 3.0 - :

5. USB - : 3m+ , - : - : ≤1.5m , ()

7.3.2 Q8: USB 3.2 Gen 2x2 Type-C ?

A: , Type-C

: - USB 3.2 Gen 2x2 (2 TX/RX) - Type-A 1 TX/RX - Type-C 24 2

:

USB	Type-A	Type-C
USB 3.0 (Gen 1)	5 Gbps	✓
USB 3.1 Gen 2	10 Gbps	✓
USB 3.2 Gen 2x2	20 Gbps	✗
USB4	40 Gbps	✗

7.3.3 Q9: USB4 Thunderbolt 4 ?

A: Thunderbolt 4 USB4 "

:

USB4	Thunderbolt 4
20 Gbps(40)	40 Gbps
PCIe	(0-32G)
	32 Gbps
	2x4K
DMA	VT-d

:- **eGPU** → Thunderbolt 4 - → USB4 - **USB** → USB 3.2

: 4 Thunderbolt vs USB4

7.3.4 Q10: USB 3.0 USB 2.0, ?

A: ,

:



:

USB 3.0	USB 3.0	USB 3.0	5 Gbps ✓
USB 3.0	USB 2.0	USB 3.0	480 Mbps ⚠
USB 3.0	USB 3.0	USB 2.0	480 Mbps ⚠
USB 2.0 U	USB 3.0	USB 3.0	480 Mbps ⚠

[!IMPORTANT]

!

USB 3.0, USB 2.0

7.4

7.4.1 Q11: Type-C ?

:

1.

3A	15W (5V 3A)	5A E-Marker
5A E-Marker	100W (20V 5A)	✓
()	5-10W	,

2. - : PD, VOOC, - : 5-10W() - :

3. / - : : - :- () - - ,

4. - : 5V 1A - : 5W - : (18W+)

5. - : , - : / > - :

7.4.2 Q12: 65W ?

A: ,**USB PD** :

```
sequenceDiagram
    participant C as 65W PD
    participant P as
    C->>P: 1. , :\u003cb>\u003e5V/3A, 9V/3A, 15V/3A, 20V/3.25A
    P->>C: 2. , 9V 2A (18W)
    C->>P: 3. , 9V 2A
    Note over C,P: 65W\u003cb>\u003e
```

: - ✓ : ✓" - : PD, 5✓1-2A - : ✓ - :
 :

65W PD	iPhone 14 Pro	27W	iPhone	27W
65W PD	11	27-45W	PD	
65W PD	AirPods	5W	,	
65W PD	MacBook Air	65W	✓	

[!TIP] : , **65-100W PD** , ,

7.4.3 Q13: "100W", ?

:

1.

: Anker 100W 3

	C1	C2	A	
C1	100W	-	-	✓
C1 + C2	65W	30W	-	⚠
C1 + C2 + A	45W	30W	18W	⚠ 100W

2. - 3A 100W : 60W (20V 3A) - : **5A E-Marker**

3. - 100W, 65W - : 65W

4. **PD** - : 5V 9V 15V 20V - : 12V() - : 9V,

[!WARNING] "100W" , **100W** ,

7.4.4 Q14: Type-C ?

:

1. - OPPO VOOC VOOC, USB PD - : 5V 1A - : USB PD

2. **C to C** - C to C , E-Marker - , - :

3. - CC - - - :

4. - Type-C , - - : , ()

7.5 Thunderbolt

7.5.1 Q15: Type-C , Thunderbolt ?

A: , Thunderbolt

:

1. - ✓ ⚡ = Thunderbolt - = USB-C

2.

macOS:

Apple → → → Thunderbolt

Windows:

→ → "Thunderbolt Controller"

3.

Thunderbolt			
Thunderbolt 4	TB4/TB3	✓	
Thunderbolt 3	TB4/TB3	✓	TB3
USB4	TB	⚠	PCIe
USB 3.2	TB	⚠	USB , TB

[!IMPORTANT] eGPU

Thunderbolt

USB-C

7.5.2 Q16: Thunderbolt

, ?

6: :**1:** - ⚡ - /**2:** - Thunderbolt ⚡ () - (≤0.8m, ≤2m)**3:****Windows:** - Intel Thunderbolt Software -**Mac:** - macOS**4: BIOS****Windows PC:** - BIOS(F2/Del) - Thunderbolt - "Thunderbolt Support" - "Thunderbolt Boot Support"()**5:****Windows 10/11:** - → → Thunderbolt - Thunderbolt**Mac:** - → → Thunderbolt - ""**6:** - (Thunderbolt) - eGPU

: ,

7.5.3 Q17: Thunderbolt

? ?

A: ,**Thunderbolt** :

	>0.8m	+¥100-300
E-Marker		+¥30-50
,		+¥20-50
,		+¥30-80
Intel		+¥50-100

: - ✓ (charging <60✓) - ✓SB () - (<0.5m)

Thunderbolt : - **X** 40 Gbps **X** - eGPU **X** **X** **X** 100W - (**>1m**)
 [!CAUTION] **¥20** **¥20000** eGPU !

7.6

7.6.1 Q18: "SS" "SS 10" "5A" "E-Marker" ?

A:

:

	USB 2.0	480 Mbps
SS	SuperSpeed	5 Gbps (USB 3.0)
SS 10 SS+	SuperSpeed 10	10 Gbps (USB 3.1 Gen 2)
SS 20	SuperSpeed 20	20 Gbps (USB 3.2 Gen 2x2)
USB4 40	USB4	40 Gbps
⚡ Thunderbolt		40-120 Gbps

:

3A	3A	60W (20V 3A)
5A 50	5A	100W (20V 5A) , E-Marker
EPR	5A	240W (48V 5A) (PD 3.1)

E-Marker : - : () - : 5A USB 3.x/4 E-Marker - : "5A" "E-Marker"
 : - **✓** : "✓" - : "SS **✓**" "SS 20" - : "USB-IF" "Thunderbolt"

7.6.2 Q19: ?

A:

:

	5A PD	¥30-60
U	USB 3.0	¥20-40
SSD	USB 3.2 Gen 2	¥60-120
	USB-C	¥80-150
eGPU	Thunderbolt 4	¥200-500

: - **X** " **X** " → **✓** " " " → " " " →

: 1. (/ / Thunderbolt) 2. 3. () 4. (USB-IF Thunderbolt)
 [!TIP] : ¥50-100 USB 3.2 Gen 2(10 Gbps)+5A , 95%

7.6.3 Q20: / SSD?

:

(1TB)					
	HDD	USB 3.0	~150 MB/s	¥300-500	Elements
	SATA SSD	USB 3.1 Gen 2	~500 MB/s	¥500-800	T5 Extreme
4K	NVMe SSD	USB 3.2/USB4	1000-2000 MB/s	¥800-1500	T7 OWC Envoy
8K/	NVMe SSD	Thunderbolt 4	2000-3000 MB/s	¥1500-3000	OWC Envoy Pro Acasis

:

1. vs - 512GB: - **1TB:** () - 2TB: , - 4TB+: ,
2. - / : HDD SATA SSD - : NVMe SSD(≥1000 MB/s) - : Thunderbolt SSD
3. - **SSD:** ! - **HDD:** ,
4. - : WC - : aigo - ()

7.7

7.7.1 1: Type-C = +

- X** : Type-C ,
- ✓** : Type-C , : - Type-C USB 2.0(480 Mbps) - 5W(5V 1A)
 : iPhone 15 - : Ty**✓**-C - : **480 Mbps**(USB 2.0)X - iPhone 14 Pro(Lightning) !
 : /

7.7.2 2: USB 3.0

- X** : USB
- ✓** : , ! : - ! USB 3.0 - USB 2.0
 : 1. / 2. / 3.

7.7.3 3: Thunderbolt 3

- X** : "Thunderbolt 3"

 : Thunderbolt 3 :

	PCIe	4K
Alpine Ridge	16 Gbps	
Titan Ridge	32 Gbps	

: - eGPU: Titan Ridge **20-30%** - : **Thunderbolt 4(32 Gbps)**

7.7.4 4: ,

X : 100W " "

 : , :

100W		
iPhone 14 Pro	27W	27W()
11	55W()	27W(PD)
MacBook Air	30W	30W
MacBook Pro 16	96W	96W

;

7.7.5 5:

X : " "

: - : - : ,

- : 1. ✓ (USB-IF Thunderbolt) 2. (✓ SS 10) 3. (Anker Belkin Apple) 4.

7.7.6 6: USB PD " "

⋮

: 140W MacBook Pro iPhone - : 140W - iPhone : 9V 3A (27W) - :27W()

PD

7.7.7 7: Thunderbolt 4 Thunderbolt 3

X : TB4 TB3

 : , 40 Gbps

TB4 : - : TB3 16G PCIe,TB4 32G - : - : 2x4K DMA

: - TB4(" ", " " , " - " , TB4()).

7.8

7.8.1 USB



7.8.2

:

1	5A E-Marker
2	
3	PD /
4	
5	
6	,

7.8.3

:

1. - (U) - CrystalDiskMark
2. - Windows: → - Mac: → USB
3. - (SS SS 10) -
4. - () : - () : - ()
5. - - - -

7.9

7.9.1 USB

10GB				
USB 2.0	High Speed	480 Mbps	~5	Type-A/B/C
USB 3.0	SuperSpeed	5 Gbps	~30	Type-A/B/C
USB 3.1 Gen 2	SuperSpeed 10	10 Gbps	~12	Type-A/C
USB 3.2 Gen 2x2	SuperSpeed 20	20 Gbps	~6	Type-C
USB4	-	40 Gbps	~3	Type-C
Thunderbolt 3/4	-	40 Gbps	~3	Type-C
Thunderbolt 5	-	120 Gbps	~1	Type-C

7.9.2 USB

USB 2.0	5V	0.5A	2.5W	
USB 3.0	5V	0.9A	4.5W	
USB BC 1.2	5V	1.5A	7.5W	
USB PD	5-20V	5A	100W	/
USB PD 3.1 EPR	5-48V	5A	240W	/

7.9.3

	Type-A	Type-C USB 2.0	Type-C USB 3.x	USB4	Thunderbolt
Type-A (USB 2.0)	✓ 480M	✓ 480M	✓ 480M	✓	✓
Type-A (USB 3.x)	✓	✓ 480M	✓	✓	✓
Type-C (USB 2.0)	⚠	✓ 480M	✓	✓	✓
Type-C (USB 3.x)	⚠	✓ 480M	✓	✓	✓
USB4	⚠	✓ 480M	✓	✓	⚠
Thunderbolt 4	⚠	✓ 480M	✓	✓	✓

✓ ⚠ ✗

|

7.9.4

:

CrystalDiskMark	Windows	/U
ATTO Disk Benchmark	Win/Mac	
POWER-Z KT002		USB / ¥300-500
USB Device Tree Viewer	Windows	USB
System Information	macOS	USB/TB

:- USB-IF - Thunderbolt

:- USB-IF - Thunderbolt - USB PD

7.10

USB Thunderbolt , :



, : 1. FAQ 2. 3.

:- 2 : USB - 3 : USB - 4 : Thunderbolt - 5 :